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# **An accelerated method of developing DBT projects using CDIO partner institutions as parallel processors**

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## **ABSTRACT**

The cycle of the academic year impacts on efforts to refine and improve major group design-build-test (DBT) projects since the time to run and evaluate projects is generally a full calendar year. By definition these major projects have a high degree of complexity since they act as the vehicle for the application of a range of technical knowledge and skills. There is also often an extensive list of desired learning outcomes which extends to include professional skills and attributes such as communication and team working. It is contended that student project definition and operation, like any other designed product, requires a number of iterations to achieve optimisation. The problem however is that if this cycle takes four or more years then by the time a project's operational structure is fine tuned it is quite possible that the project theme is no longer relevant. The majority of the students will also inevitably experience a sub-optimal project experience over the 5 year development period. It would be much better if the ratio were flipped so that in 1 year an optimised project definition could be achieved which had sufficient longevity that it could run in the same efficient manner for 4 further years. An increased number of parallel investigators would also enable more varied and adventurous project concepts to be examined than a single institution could undertake alone in the same time frame.

This *work-in-progress* paper describes a parallel processing methodology for the accelerated definition of new student DBT project concepts. This methodology has been devised and implemented by a number of CDIO partner institutions in the UK & Ireland region. An agreed project theme was operated in parallel in one academic year with the objective of replacing a multi-year iterative cycle. Additionally the close collaboration and peer learning derived from the interaction between the coordinating academics facilitated the development of faculty teaching skills in line with CDIO standard 10.

## **KEYWORDS**

Design-Build-Test, project based learning, collaborative optimisation

## 1. Background

The UK & Ireland region of the CDIO Initiative hold on average a one-day meeting two times per year to share experiences of CDIO curriculum reform and to learn from each other aspects of engineering education best practice. The hosting of these meetings cycles around the most active collaborators in the region and the agenda for the day usually includes a tour of the project workspaces and discussion of issues related to this challenging aspect of CDIO implementation. During the meeting held at Aston University in May 2013 an idea was floated of combining the efforts of the group on project development to better utilise the network of collaborators which had become well established in the region and to provide an extra incentive and focus for future regional meetings. This idea had grown out of a recognition of shared problems and challenges relating to Design-Build-Test (DBT) projects. Not least of these problems was the need for suitable workspaces, materials and manufacturing resources as well as a sizeable budget. While each institution was recognised to be delivering high quality experiences in this area there was also a frustration that the year-long feedback loop typical of such projects restricted further optimisation from being realised.

## 2. Parallel processing rationale

While many of the DBT projects at the various institutions were believed to have broadly similar objectives closer examination of the learning outcomes showed considerable differences which were also expressed with very different levels of detail across the institutions. The idiom of comparing apples and oranges (or apples and pears in some countries) comes to mind here and, while there is always something to be learnt from closely observing the practice of others, the contention of the group was that this could be enhanced by locking down one of the variables, namely the project theme.

The intention was that by fixing on a common project theme a more systematic investigation of some of the other variables in the delivery of DBT projects could be conducted in parallel. Additionally implementations and outcomes could be compared during and after the year-long projects in the 2013-14 academic year. Each institution would be allowed to run the theme where it most appropriately fitted into their existing curriculum.

Recognising that this first year would not be an ideal or optimised implementation it was designated as a pilot with an objective to run a more common implementation with an inter-university competition element for the UK & Ireland region in the 2014-15 year. Beyond that it was envisaged that if successful the project could be extended to international collaborators with the competition element potentially being linked to the international conference.

### 2.1 Comparison of DBT Learning Outcomes

While the overall objectives of DBT projects were well understood, discussion between the collaborators revealed key differences in the specific learning outcomes (LOs) of the relevant modules/courses at the various institutions. By way of illustration:

#### ***QUB - On successful completion of this module the students will have:***

- *evolved a design from the conceptual stage to an associated proof of concept prototype.*
- *gained practical experience of the application of the knowledge and skills acquired in previous and concurrent modules.*

- *Communicated proposals and results in a verbal, graphical and written form.*

**Strathclyde - On completion of the module the student is expected to be able to:**

- *Appreciate the principles of project management and planning*
- *Be able to reflect on their role in a team and their interaction with team members*
- *Appreciate the importance of technical risk and health and safety management*

**Liverpool (Intellectual Abilities subsection of the LO statement) - On successful completion of the module, students should be able to demonstrate ability in:**

- *Evaluating opportunities and competitors in a marketplace.*
- *Creating product design specifications suitable for industrial application.*
- *Conceiving and quantifying unique and commercially viable design ideas.*
- *Fundamental risk analysis and decision making.*
- *Formulating, analysing and solving design problems using the principles of total design.*
- *Designing components and products using advanced CAD, materials selection software and defining manufacturing processes.*

**Aston (Intellectual Skills subsection of the LO statement) - The student will gain the following from successful completion of the module:**

- *Ability to generate an innovative design for products, systems, components or processes to fulfil new needs.*
- *Ability to apply engineering techniques taking account of a range of commercial and industrial constraints.*

For practical reasons it was decided that each institution would implement the common student project within an existing module suited to delivering the objectives of the design brief, rather than establishing new structures and objectives across institutions. This approach supported the objectives of this parallel processing development activity by allowing participants to compare and contrast different approaches.

### **3. Development of the Design Brief**

The development of the student brief was initiated at the regional meeting held at Aston University in May 2013. A draft was produced which built on the experiences of two ongoing DBT competition challenges: the Year 4 recumbent bicycle DBT competition at Queen's Belfast and the Year 1 Formula 24 competition which is part of the introductory module at Aston University.

#### **3.1 QUB Innovative Recumbent Bicycle Design Challenge 2012/13**

This was a stage 4 (final year of an integrated Master's degree) Mechanical Engineering (MEE) competition. Eight teams, each of 6 students, designed and built bicycles based on a loose brief. From the outset they were aware that they would be competing against the other teams at a final competition day with slalom, acceleration and timed circuit events (Figure 1). Other criteria against which the bicycles were judged included weight and cost of the prototype. Despite being given the same brief there was significant variation in the designs. For example, one used a drive shaft instead of a chain, another had a hybrid pedal and rowing drive system. Frame materials ranged from carbon fibre composite through steel and aluminium sections to bamboo and wooden laminates.

### 3.2 Aston Formula 24

This is a first year introductory DBT exercise taken by all students on the Mechanical Engineering and Product Design degree families. A single semester, 15 ECTS module, students would work in 12 teams of 10 to create electric vehicles. Designs were limited to wooden or tubular steel space frames, connected by fish plates, while a standard back end power train was also provided. The aim of the project was to introduce students to group work and practical project management and to show how these, coupled to scientific and technical understanding are necessary to produce a successful outcome. The final showcase of the vehicles was a time trial around campus (Figure 2).



Figure 1 - QUB recumbent bicycle



Figure 2 - Aston Formula 24

### 3.3 Development of the Common Design Brief

A number of key objectives were quickly agreed which sought to provide a challenge which enabled all students to get the type of experience gained through Formula Student (SAE) but without the expense. The main objectives therefore included:

- A theme to engage and motivate students
- A competitive element
- Be financially viable for hundreds rather than tens of students

Further discussion resulted in the addition of a fourth objective - the context of sustainability as a central theme. Over the following weeks a series of emails and telephone conversations and minor adjustments resulted in the following single page design brief which became the basis for the pilot implementations.

#### The Challenge (4 – 6 students per group)

- *Conduct a design investigation to explore how individuals might move around urban environments independently but with a much lower carbon footprint. The power source, ergonomic configuration, and commercial aspects will all need to be considered as well as the health and safety aspects of how such a vehicle might integrate into existing and future urban infrastructures.*

- *The vehicle should be developed for a future lifestyle context of energy self-sufficient households. The solution should therefore aim to be capable of completing a return trip to the home without the need to “refuel”.*
- *Design Considerations:*
  - *Power source (human / electric / solar / other renewable)*
  - *2 / 3 / 4 / n wheeled vehicle*
  - *Range (to be determined by research / investigation)*
  - *Kg load and m<sup>3</sup> storage capacity (to be determined by research / investigation)*
  - *Sustainability (manufacture, operation, recycling, reuse, disposal)*
  - *Weather protection (e.g. rain in Ireland, heat and humidity in Malaysia)*
- *Deliverables: (each university to pick some or all from the list below to suit their own context)*
  - *Design-Build-Test a full size, low cost mock-up (e.g. timber frame and polymer sheet )*
  - *CAD design (and FEA) of mass production ready chassis*
  - *CAD model and visualisation of bodywork and full assembly*
  - *Business case plan (for pitching to venture capitalists)*
  - *Design / project report*

#### 4. Pilot Implementation of the Common Project

In preparation for the end-of-project comparative evaluation of the student learning / faculty teaching experience, an audit of the different implementations was completed (Tables 1 & 2 below).

Table 1 – Comparison of study level and module

Institution	Stage	MEng/BEng	Students	Discipline	Groups	ECTS
Aston	4	MEng	3	MEE	1	20
Liverpool	2	MEng & BEng	120	MEE & General	20	7.5
Strathclyde	5	MEng	5	MEE	1	20
QUB	3	MEng	50	MEE	10	15

Table 2 – Comparison of assessment and resources

Institution	Prototype	Report pages	Competition	% group / individual assessment	m <sup>2</sup> “den” workspace / group	Budget / group (GBP £)
Aston	Concept, CAD & Functional	80	none	40/60	12	600
Liverpool	CAD & Manufacturing Pack	10+20+40	none	100/0*	0	0
Strathclyde	Concept, CAD & Functional	51	none	100	14	500
QUB	Concept & CAD	30	local	50 / 50	16	300

\* All group assessment subject to peer moderation of 30% to give individual mark.

#### 4.1 QUB Implementation

This involved stage 3 MEng students and had 2 distinct phases, which ran in line with the 2 semesters of the academic year. The overall objective was to conduct a design investigation to develop an innovative solution to the CDIO design challenge document. In semester 1 the target was to design, build and test a proof of concept prototype, while semester 2 focused on detail design (CAD) and analysis (CAE). Teams of 5 had their own dedicated project dens (4m x 4m) and a budget of £300 which was mostly used to purchase materials for the concept prototype. Some standard components such as gears and wheels were purchased, or resourcefully salvaged. The main competitive element was the poster and prototype exhibition in week 12 (immediately before the Christmas holiday) which also served to mark the end of phase 1 and start of phase 2. The final design was not manufactured but the design detail, informed by phase 1, was described in a 30 page technical report and associated General Arrangement (GA) drawing. Individual interviews, an individual design critique and individual continual assessments by the 2 supervisors for each group represented 50% of the marks awarded for each student.

#### 4.2 Liverpool Implementation

This approach to the common project involved Year 2 students on a design module taken by all 120 Mechanical and General Engineering students, working in teams of 6. Students began by preparing a PDS; progressing through concept development, analysis and selection; creation of fully embodied 3D CAD; using Cambridge Engineering selector for materials and manufacturing process selection; and finally creating detailed technical drawings and a manufacturing pack. All assessment was group assessment, but the three written reports were all subject to peer moderation using WebPA: Students were able to give variation of each others' marks by up to 30% to reflect individual contribution.

#### 4.3 Aston & Strathclyde Implementations

Both of these institutions ran a similar version which offered the design brief as one of many which could be selected by students from a list. A group of students interested in the theme



then worked over 2 semesters towards producing a fully functional prototype. There was just a single team at each of these institutions.

## 5. Examples of Pilot Project Deliverables

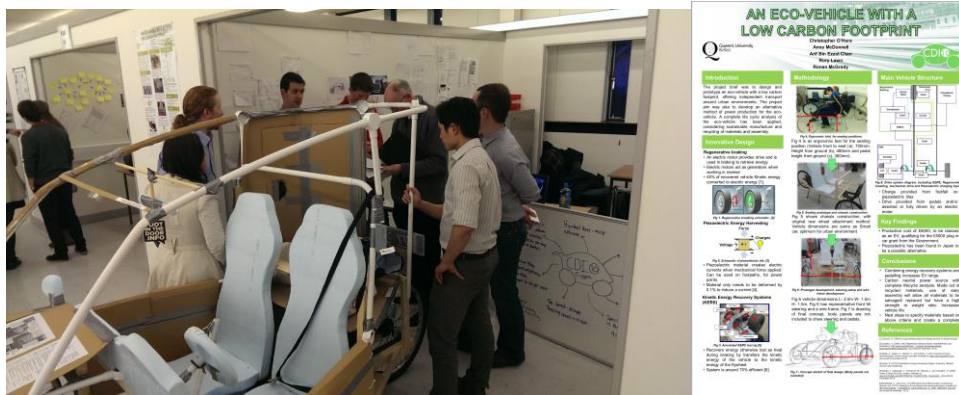


Figure 3 – QUB - Interim concept prototype and poster exhibition



Figure 4 – Aston – Concept mockup to CAD design to fabricated chassis

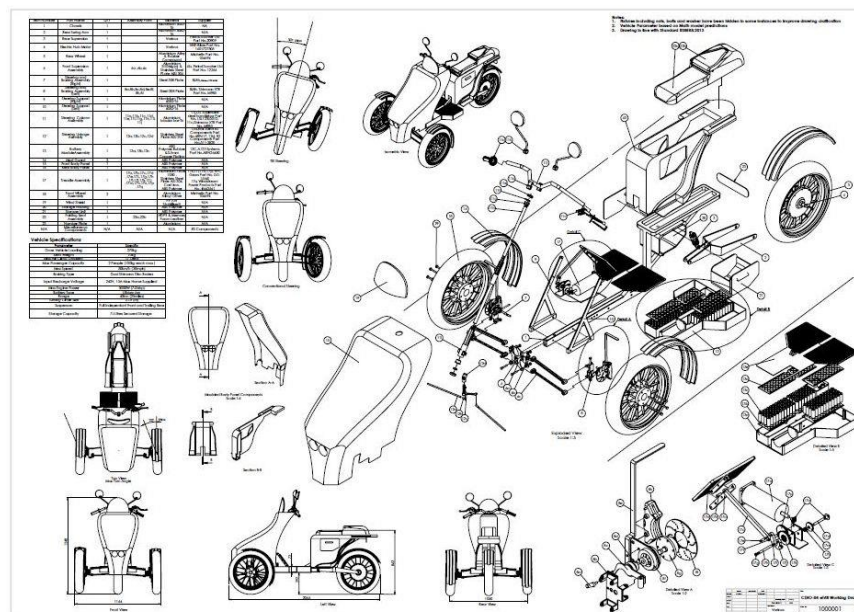


Figure 5 – QUB - Sample A0 General Arrangement (GA) drawing



## **6. Pilot Project Evaluation Methodology**

The formal evaluation of the parallel projects has still to take place. The column headings from Table 2 above will provide initial points to compare and contrast, seeking to identify what worked well and what could be improved further. This analysis will be backed up a standardised questionnaire which will be issued to all participating students across the institutions at the end of their projects. These will be supplemented by individual interviews to clarify and expand on any issues which the students raise in the more open ended questions. Academic Faculty and their supporting technical staff will also be consulted about their experience of the pilot project implementation.

While the projects have been ongoing there have been several opportunities for the collaborators to view the implementations at other institutions. By scheduling two UK & Ireland regional meetings in January 2014 at QUB and April 2014 at Liverpool, the two universities where the implementations involving most students were taking place, a better understanding of many of the relevant issues has already been gained.

Table 3 below catalogues some early observations on the student learning and faculty teaching experience of this common project, delivered in four distinct modes at four separate universities.

## **7. Further Work**

The initial intention at the genesis of this project in May 2013 was to be in a position by September 2014 to run a competition across multiple institutions which would operate on a single design brief and deliverables. The viability of such is at this point still under consideration but significant obstacles in the form of differences in curricula structure present barriers yet to be addressed.

Another objective was to accelerate the optimisation of a design brief which would have longevity, present a significant challenge and developmental experience for students, and achieve this within a budget that made it viable for large cohort sizes. The preliminary findings suggest that more progress on this objective has been made than might have been achieved in isolation.

It has become clear that this “parallel-processing” approach to teaching development has already been effective, and that it has the potential to enhance collaborative activity across the wider CDIO consortium. The authors look forward to completing this pilot study and reporting their conclusions in 2015, before exploring the opportunity to involve international partners in further collaborative development of this type.

Table 3: Preliminary Observations on Implementation

<b>Queen's University Belfast</b>	<ul style="list-style-type: none"> <li>• Project space is a significant issue. Permanently assigned 16m<sup>2</sup> project booths worked well but are not a viable option in future years as growing student numbers and increased DBT content in curriculum will require project spaces to become shared and flexible “hot desk” type facilities.</li> <li>• Having a common design brief among locally competing teams resulted in a good variety of innovative design concepts.</li> <li>• Not having a final competition event proved something of an anticlimax compared to the previous recumbent bicycle project.</li> <li>• By not building a functional prototype the cost per team was reduced significantly and the School's engineering workshop was not under as much pressure to deliver machined components. On the down side the students missed out on a valuable learning experience.</li> </ul>
<b>University of Liverpool</b>	<ul style="list-style-type: none"> <li>• The purpose of this module is to put year 2 students through a detailed, team design process for the first time in their lives. They are challenged by this and learn a lot from it, but do not enjoy the satisfaction of building a prototype of their design. Further an early design prototype would improve their design evolution. It is likely that we will adopt the early, non-functional prototype manufacture employed at QUB to enhance this module.</li> <li>• All students are trained in 3D CAD in Year 1 and this year 2 module is the first chance they get to put this to real use. They learn a lot from developing a group model of a complex assembly in CAD, but tend to focus too much on this design embodiment and not enough on the wider design process.</li> <li>• All assessment is on a group basis and many students resent being awarded the same mark as the less capable, less motivated, less involved members of their team. Peer moderation of the group mark to give an individual mark partially addresses this issue but more needs to be done. Thus far groups have been designed to include students from all ability ranges. Group formation will be reviewed to consider grouping students of similar ability.</li> <li>• Students excited and motivated by being part of a multi-university activity, but are keen to undertake identical format project in competition, and to interact with other teams.</li> </ul>
<b>Aston University</b>	<ul style="list-style-type: none"> <li>• As a single group, project space is not necessarily a major issue, however dedicated space needed to be provided to the group for at least part of the academic year.</li> <li>• Single group lacked direct competition but were keen to hear how groups at other Universities were doing.</li> <li>• Lack of other groups doing the same project allowed group to slip in their progress as there was little direct calibration.</li> <li>• At present it remains to be seen whether full functionality will be achieved.</li> </ul>

## BIOGRAPHICAL INFORMATION

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